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Title: A Novel High Frequency, High Bandwidth, Three Phase Mach Zehnder Optical Data Link

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A Novel High Frequency, High Bandwidth, Three Phase Mach Zehnder Optical Data Link

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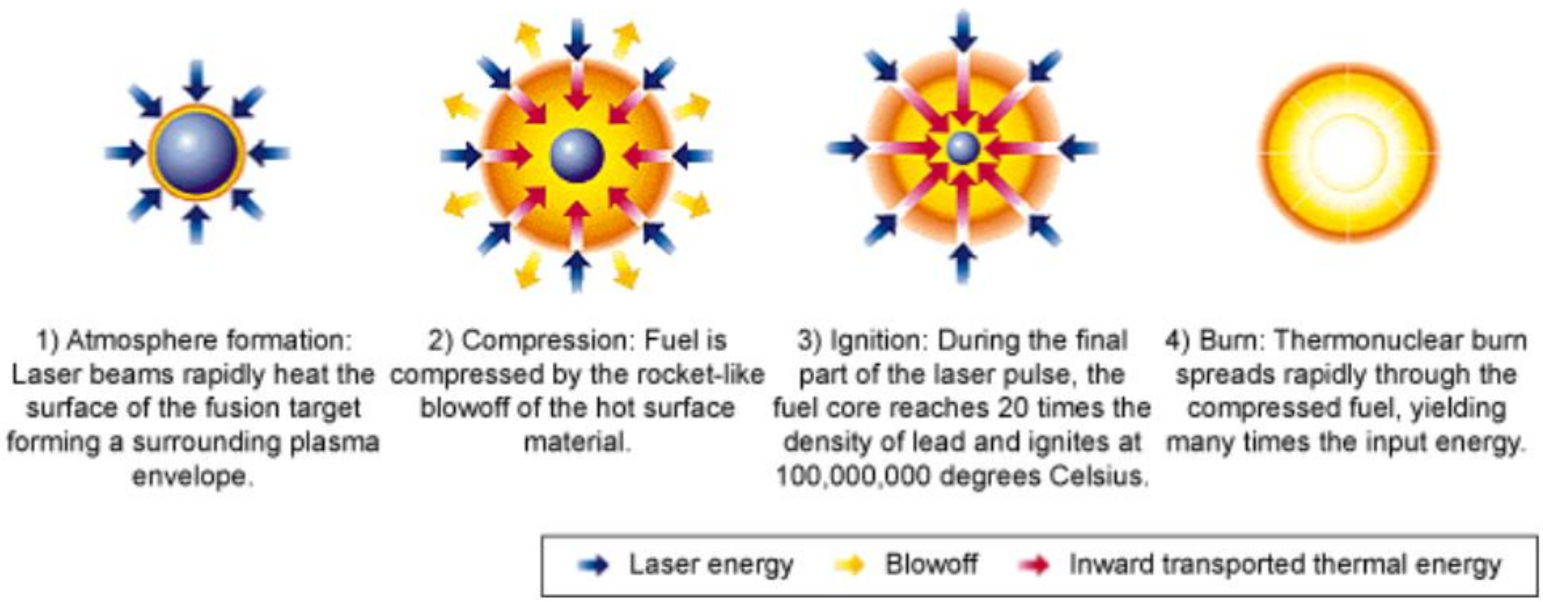
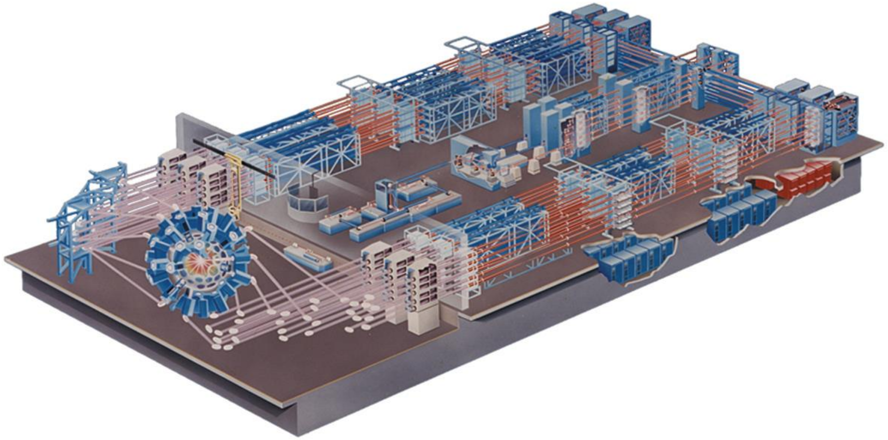
Inertial Confinement Fusion (ICF)

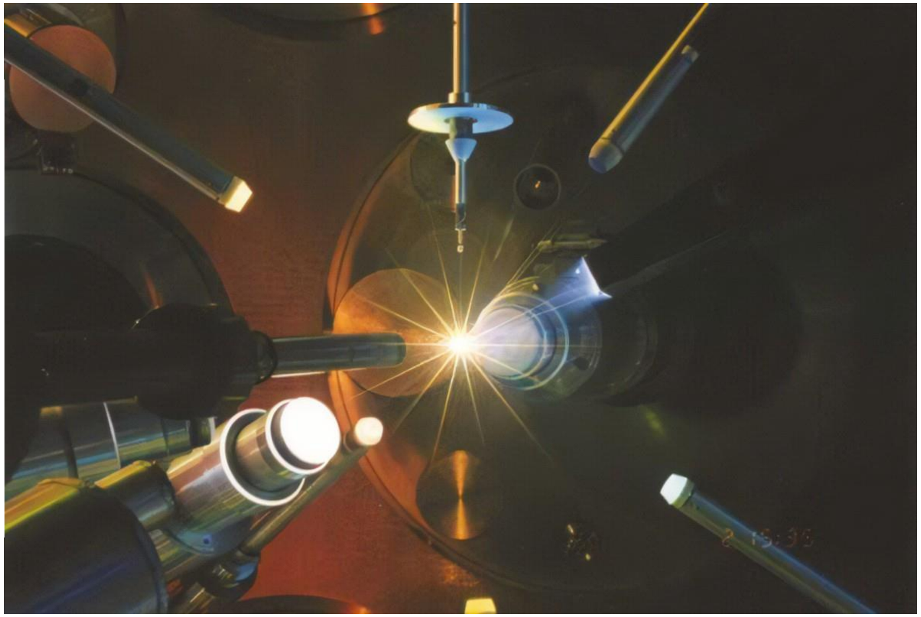
1. Incident lasers heat up a DT fuel filled capsule
2. The outer high density carbon layer burns off
3. Rapid compression of inner layers
4. Fusion of DT fuel



Inertial Confinement Fusion (ICF)

- Several places have constructed large test chambers for experimenting with Inertial Confinement Fusion, including the National Ignition Facility (LLNL) and OMEGA (LLE)
- Each facility has many diagnostic measurement devices being used to evaluate different aspects of the experiment (e.g. Neutron yield, temperature, density, reaction rate, etc.)

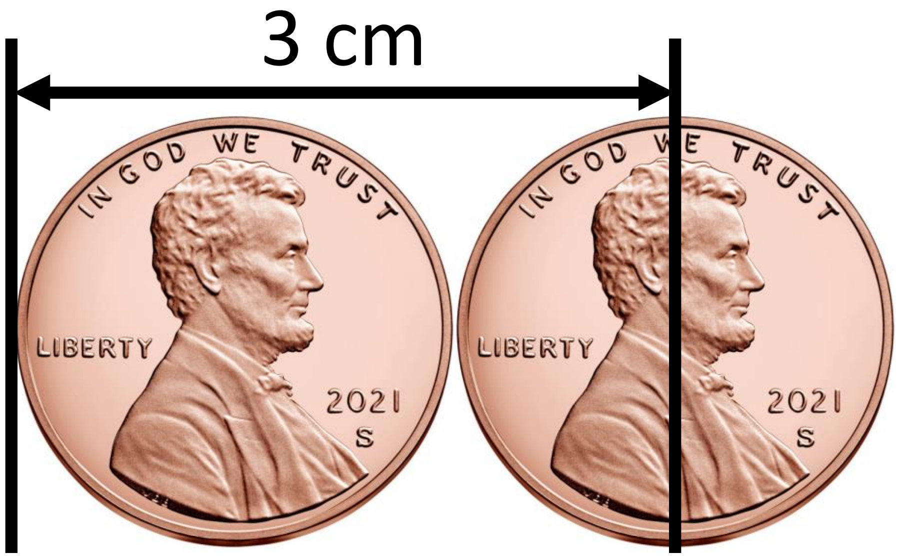




High Bandwidth Signals

- The fusion reactions that take place at the facilities mentioned happen at a very fast rate and dissipate quickly with very high yields of gammas/neutrons

- The resulting signal from the PMT has a FWHM on the order of 100 picoseconds, which is the time it takes light to travel 3 centimeters



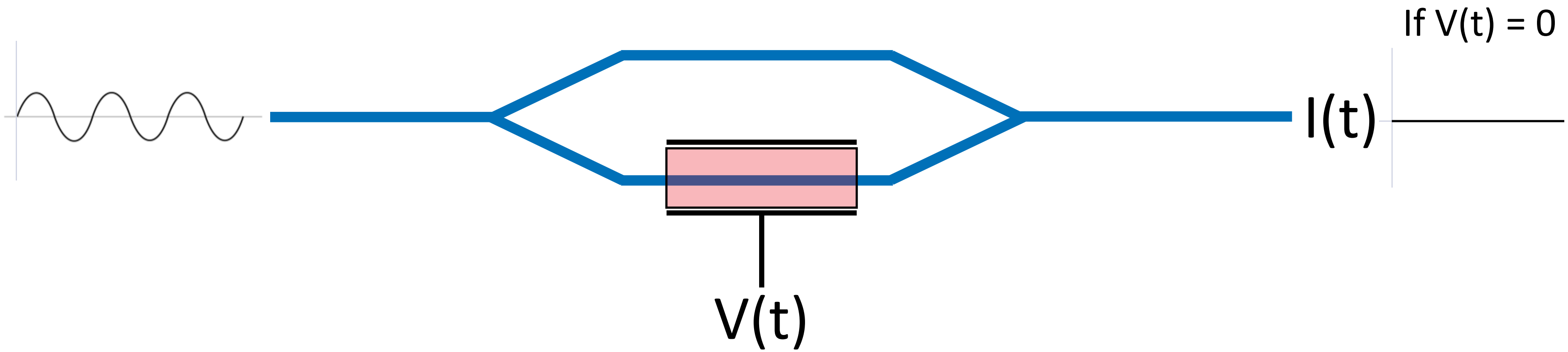
Data Transfer Issues

- A “shot” is an event where a single fuel capsule is imploded
- Radiation and the EMP from laser pulse forces data collection equipment to a distanced shielded room to prevent damage
- Thus the signal must travel approximately 150 Feet
- Higher frequency signals and longer cable length degrades the signal rapidly
- The solution was to convert the electrical signal to an optical signal for transmitting over the large distance

Mach Zehnder Modulator Solution

- A Mach Zehnder Modulator has an optical signal constantly passed through a piezoelectric crystal to introduce a phase shift
- An electric field induced by an input voltage causes this crystal to stretch, and in turn modulates the optical signal
- This modulation can be measured and then an input voltage signal can be reconstructed

$$I(t) = A + Bsin\left(\frac{\pi}{V_\pi}V(t) + \varphi\right)$$



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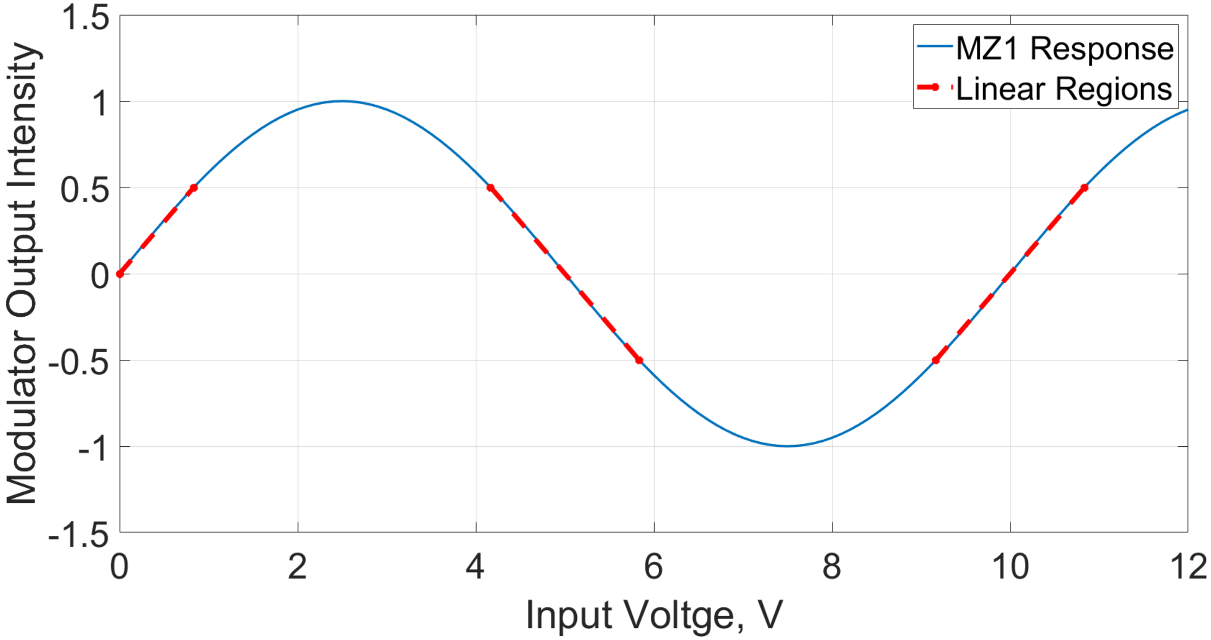
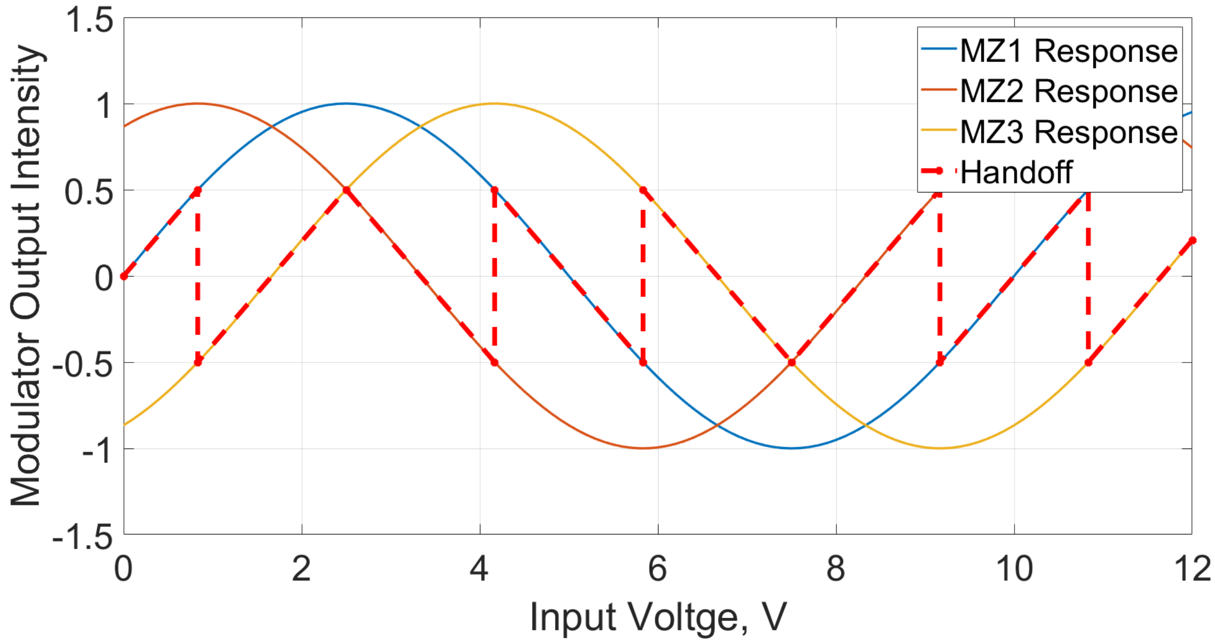
Dynamic Range Issue

- The Mach Zehnder Modulators do have limitations
- The dynamic range of an MZ modulator is limited to certain “linear regions” of the MZ response, as shown below
- Outside of these regions the signal is effectively lost due to insensitivity



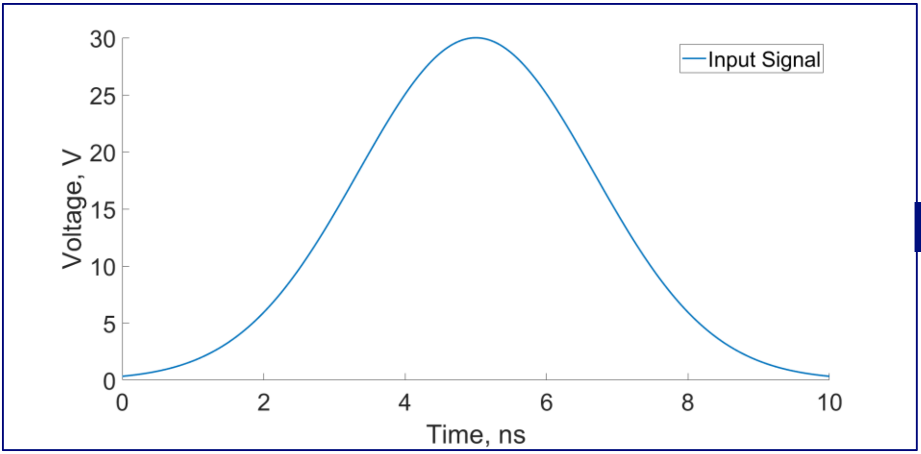
3-Phase Mach Zehnder Solution

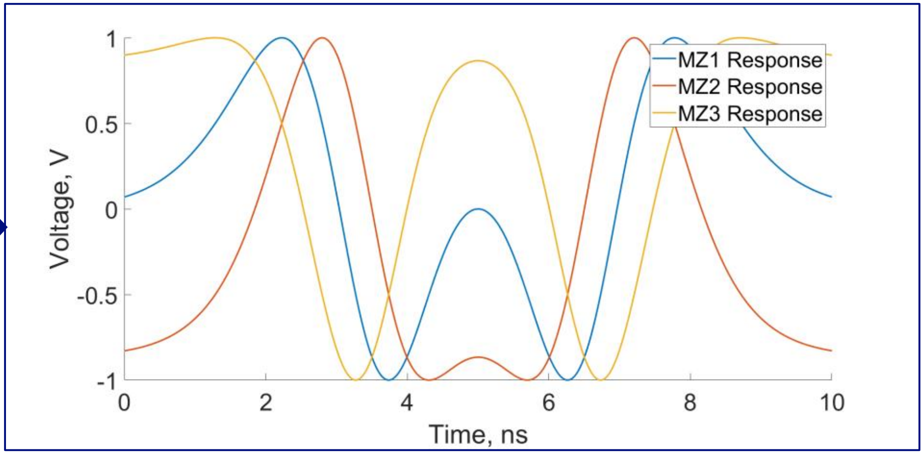
- The goal of the 3-Phase Mach Zehnder idea is to remove the dynamic range limitation of the Mach Zehnder
- We would use only the linear region of a single modulator and “hand off” the signal between the other modulators which and stitch together a signal



Reconstruction Program – Initial MZ Output

- The reconstruction program has three steps
  - Demodulation
  - Unfolding
  - Stitching
- We can run through an example using simulated data based on a Gaussian input

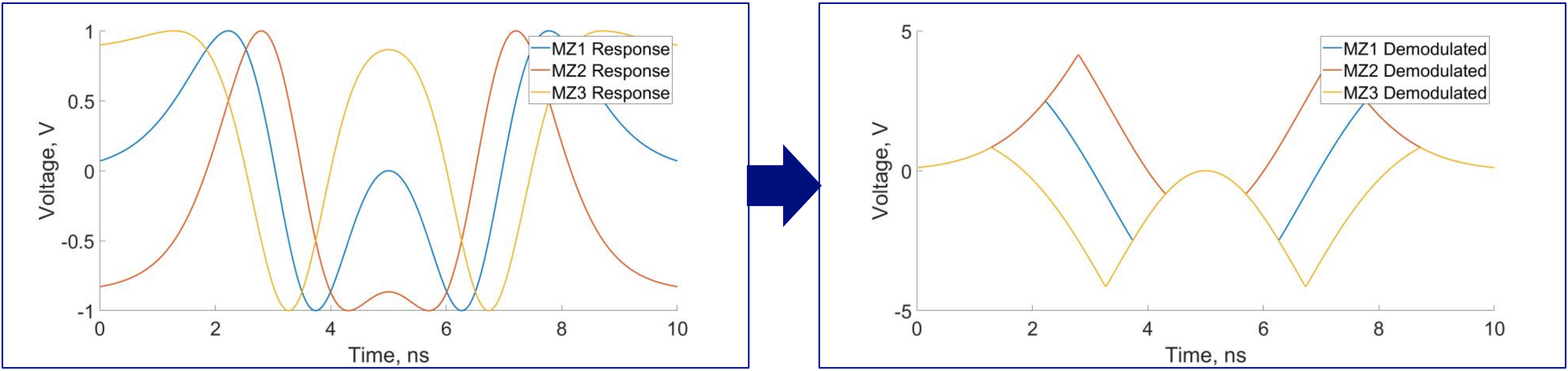




Reconstruction Program - Demodulation

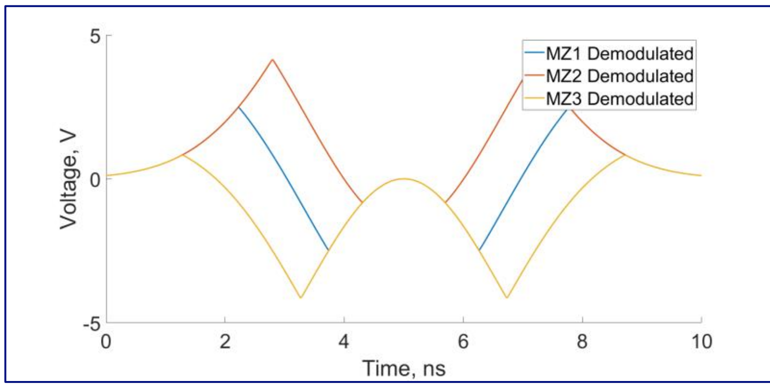
- The reconstruction program has three steps, the first of which is demodulation
- This is simply plugging the intensity output of the MZ into the inverse of the modulation equation

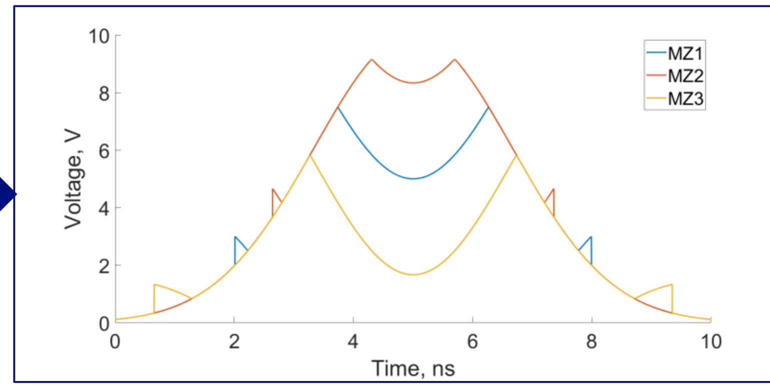
$$\mathrm{V}(t) = \frac{V_\pi}{\pi}\left[\sin^{-1}\left(\frac{1}{B}I(t) - A\right) - \varphi\right]$$

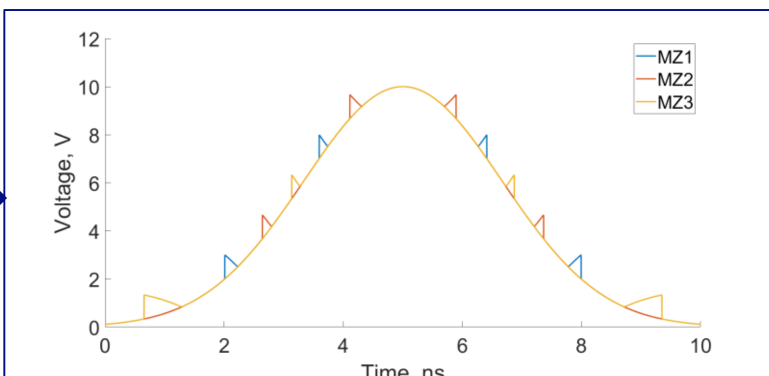


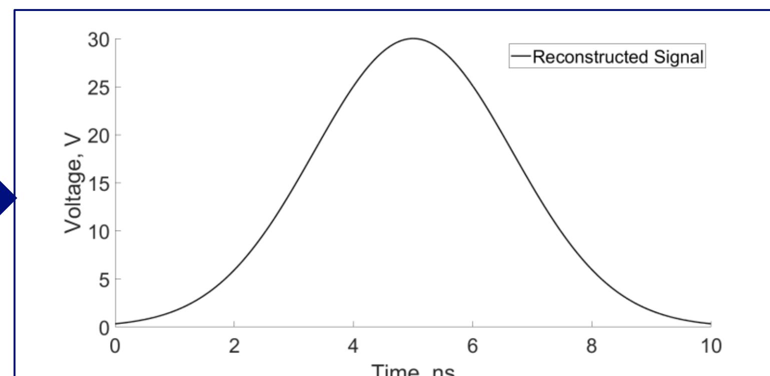
Reconstruction Program – Unfolding & Stitching

- You must then “unfold” the signal, by way of flipping the signal in between peaks around increments of Vpi in several steps
- Stitching refers to constructing a signal by selecting portions from each Mach Zehnder that are not in a “rollover” state and stitching them together



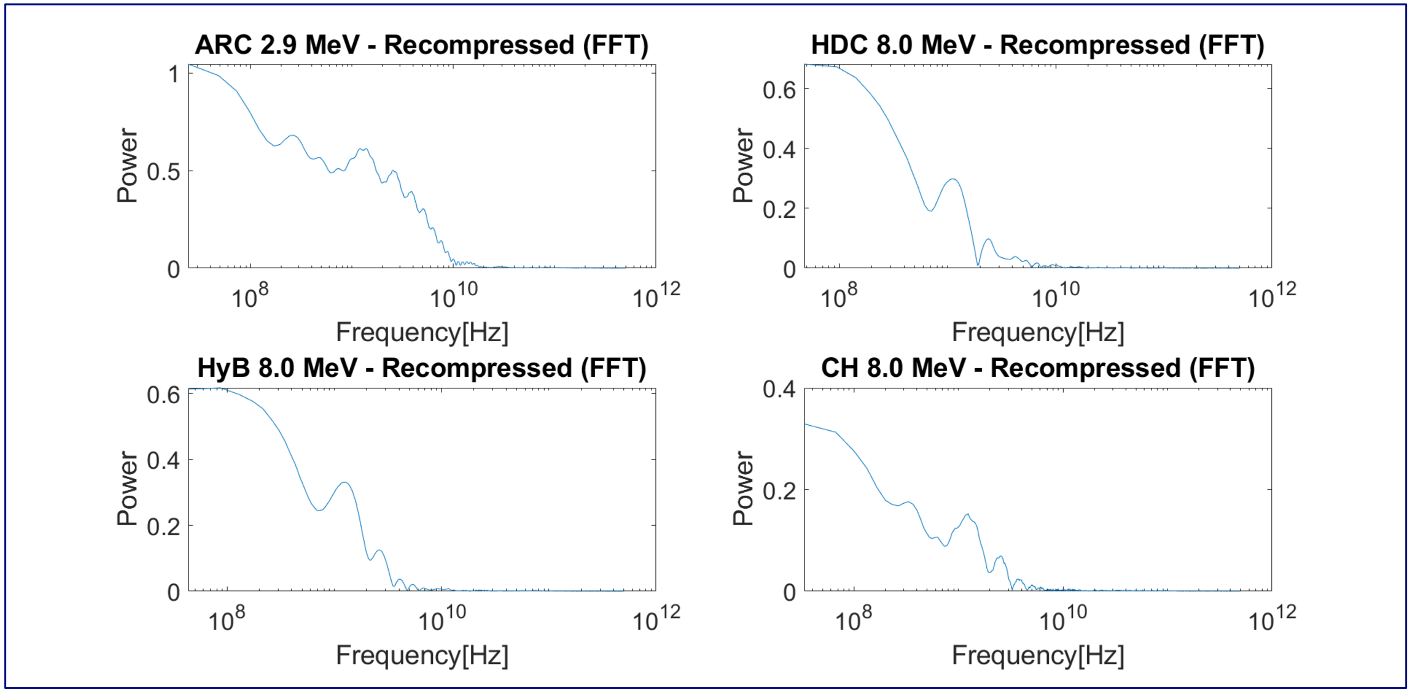






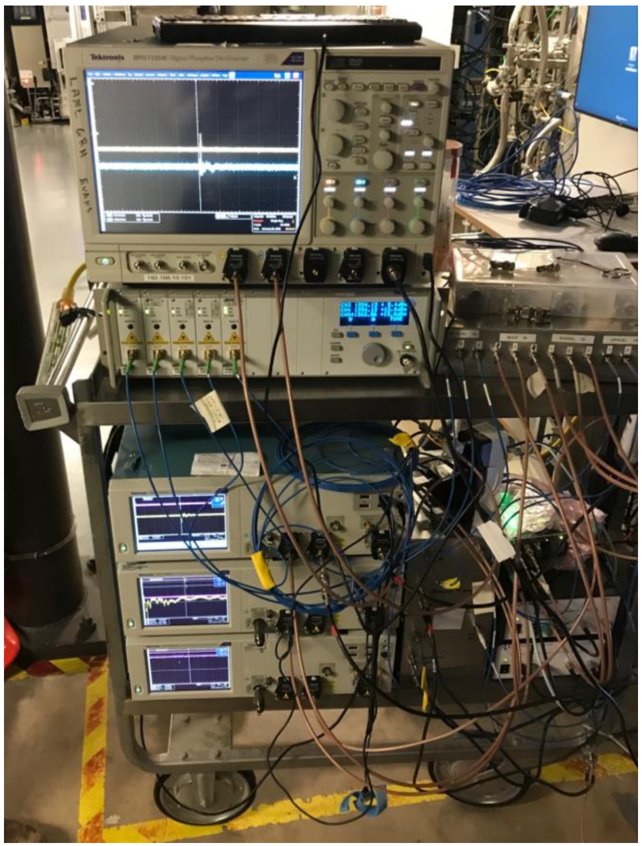
Bandwidth Needs

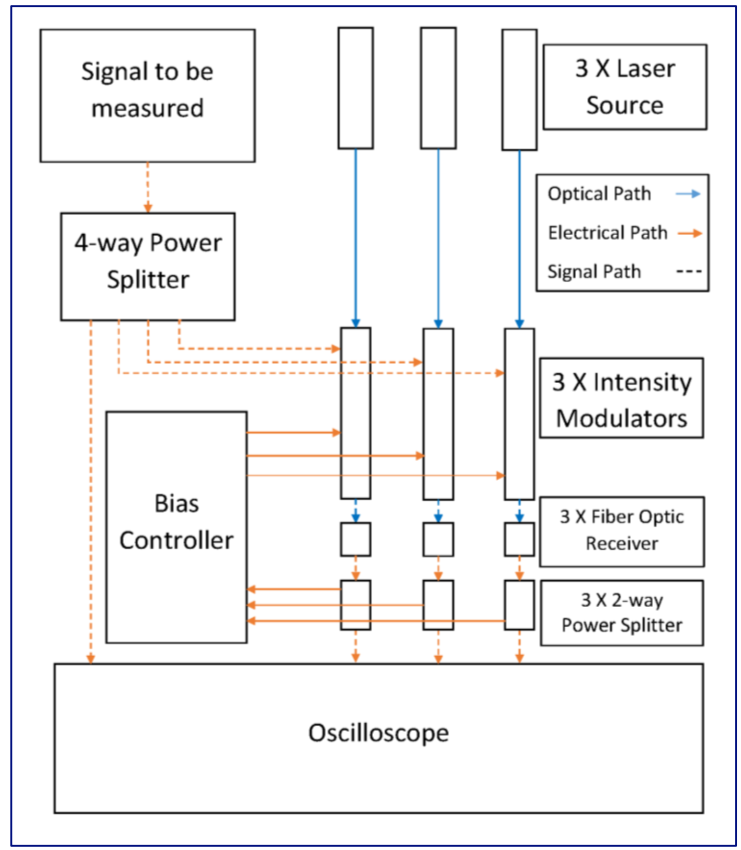
- We performed a Fast Fourier Transform on previous NIF data to get an estimate of the exact bandwidth needs
- 10 GHz is the upper range
- Our equipment is rated at 12.5 GHz or higher



Physical Setup

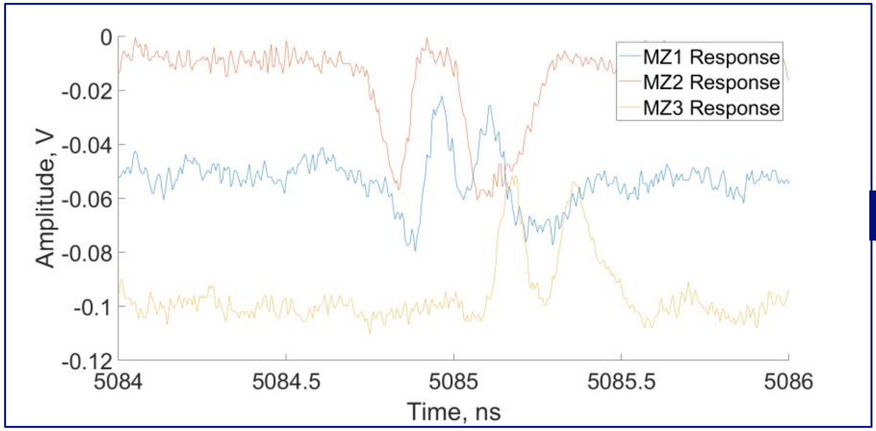
- We designed and constructed a physical setup using the bandwidth needs as a guideline for component selection, and we tested it at OMEGA

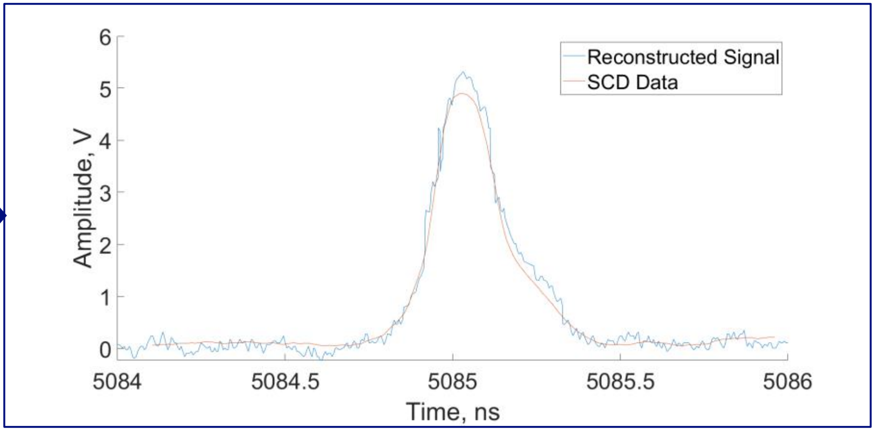




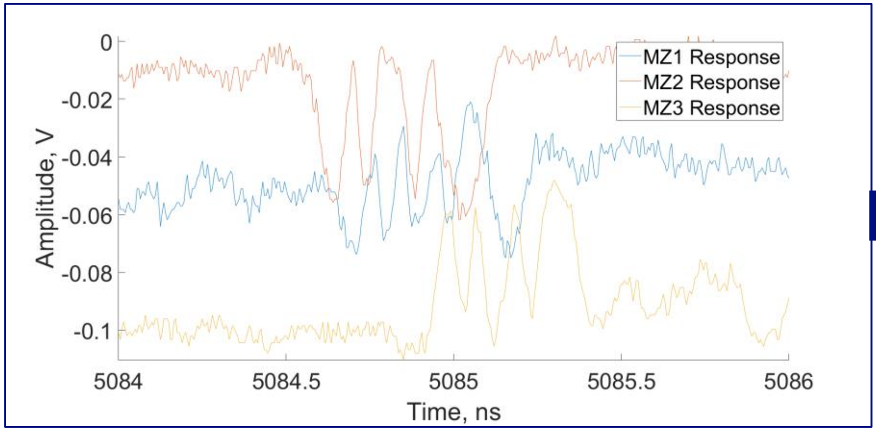
OMEGA Results

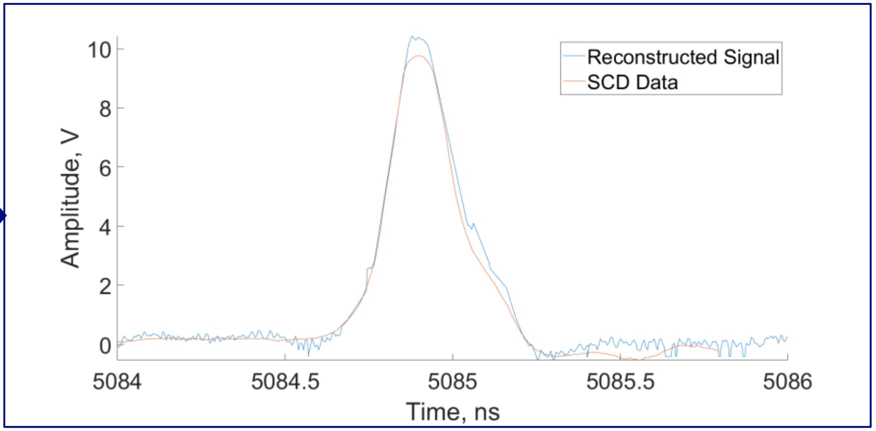
SHOT 12: 200 GS/s w/ Attenuation





SHOT 10: 200 GS/s w/o Attenuation





Summary

- ICF produces high yield, high bandwidth signals that must be sent over large distances

- A three phase Mach Zehnder modulator system helps resolve many of the issues faced with measuring these signals

- This setup requires a three step reconstruction program

- The testing results from OMEGA show this setup was successful and is ready for fielding at NIF